NAVY EXPERIMENTAL DIVING UNIT

TECHNICAL REPORT NO. 6-94

COMMERCIALLY AVAILABLE PERFORMANCE INC. REGULATORS

ENC(DV/SW) J. A. NOE

APRIL 1994

NAVY EXPERIMENTAL DIVING UNIT

2

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
321 BULLFINCH ROAD
PANAMA CITY, FLORIDA 32407-7015

IN REPLY REFER TO:

NAVSEA TA94-010

NAVY EXPERIMENTAL DIVING UNIT

TECHNICAL REPORT NO. 6-94

COMMERCIALLY AVAILABLE PERFORMANCE INC. REGULATORS

ENC(DV/SW) J. A. NOE

APRIL 1994

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

Submitted:

J. A. NOE
ENC(DV/SW), USN
Task Leader

Reviewed:

M. E. KNAFELC
CDR, MC, USN
Senior Medical Officer

B. D. McKINLEY
LCDR, USN
Senior Projects Officer

J. R. CLARKE, Ph. D.
Scientific Director

M. V. LINDSTROM
LCDR, USN
Executive Officer

Approved:

BERT MARSH
CDR, USN
Commanding Officer

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING AUTHORITY	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NEDU Report No. 6-94	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZ. Navy Experimental Diving Unit 6b. OFFICE SYMBOL (If Applicable) 03E1	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) 321 Bullfinch Road, Panama City, FL 32407-7015	7b. ADDRESS (City, State, and Zip Code)
8a. NAME OF FUNDING SPONSORING ORGANIZATION Naval Sea Systems Command 8b. OFFICE SYMBOL (If Applicable) 00C	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) 2531 Jefferson Davis Highway, Arlington, VA 22242-5160	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. 94-010 / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
(U) Commercially Available Performance Inc. Regulators

12. PERSONAL AUTHOR(S)
ENC(DV/SW) J. A. Noe

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Test Report	FROM JAN 94 TO APR 94	APRIL 1994	15

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Open-Circuit SCUBA Regulators, Cold Water Open-Circuit SCUBA Regulators, Authorized for Navy Use (ANU) list, Work of Breathing (WOB), Respiratory Minute Volume (RMV), Performance Goal Standard

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Evaluations were conducted on Performance Inc, Chapel Hill, NC, PDXL 700 and PDXL 1000 regulators, to determine which commercially available open-circuit SCUBA regulators were capable of meeting performance goal standards for Navy use. Bench testing of all candidate regulators was conducted to establish flow patterns and air delivery capacity. Unmanned testing using a breathing simulator at ventilation rates of 22.5, 40, 62.5, 75, and 90 L/min at test depths of 0 to 60 msw (0 to 198 fsw), in 10 msw (33 fsw) increments was conducted to determine work of breathing (WOB) values. Each candidate regulator model was subjected to five runs each and a mean of the WOB was established. This mean WOB value was then compared to the Performance Goal Standard of 1.37 Joules per Liter (J/L) at 60 msw (198 fsw). Testing was conducted in ambient temperature water, approximately 21°C (70°F), with a supply pressure of 10.34 MPa (1500 psi). All testing conducted determined that none of the candidate test regulators were capable of meeting the requirements for acceptance by the US Navy.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
NEDU Librarian	904-230-3100	

DD Form 1473

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

GLOSSARY

ANU	Authorized for Navy Use List (NAVSEAINST 10560.2 series)
fsw	Feet of Seawater
J/L	Joules per liter, unit of measure for "Work of Breathing" normalized for tidal volume
kPa	Kilopascals, newtons/meter^2
MPa	Megapascal
msw	Meters of Sea Water
NAVSEA	Naval Sea Systems Command
NEDU	Navy Experimental Diving Unit
OSF	Ocean Simulation Facility
psi	Pounds per Square Inch
RMV	Respiratory Minute Volume
SCFM	Standard Cubic Feet per Minute
SLM	Standard Liters per Minute
WOB	Work of breathing, a computer derived estimate of total respiratory effort obtained when breathing a regulator with a mechanical breathing simulator.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

The requirement for an open circuit SCUBA regulator with the ability to perform within the Performance Goal Standard[1] to a depth of 60 msw (198 fsw) has evolved from changes in diver mission profiles and concern for diver safety in the FLEET DIVER community.

To achieve this end, NEDU was tasked[2] to test and evaluate production models of commercially available open circuit SCUBA regulators to determine which ones meet the US Navy's demanding performance criteria.

PERFORMANCE INC., Chapel Hill, N.C., provided two candidate models for evaluation, the PDXL 700 and the PDXL 1000.

UNMANNED EVALUATION

METHODS

Unmanned evaluations of the two candidate regulator models measured Work of Breathing (WOB) levels and compared them to Performance Goal Standards[1], which represent ideal performance levels for open circuit SCUBA regulators. WOB levels are a computer derived estimate of total respiratory effort obtained when breathing a *regulator* with a mechanical breathing simulator, with units of joules per liter (J/L). Five different regulators were tested for each model. WOB averages represented the mean of the five test results.

The performance goal[1] of 1.37 J/L at 40 msw (132 fsw) with a respiratory minute ventilation (RMV) of 62.5 liters per minute (L/min) and first stage supply pressure of 10.34 MPa (1500 psi) was extended to include 50 and 60 msw (165 and 198 fsw).

Testing was also conducted at the deeper depths, at high ventilatory rates, and reduced first stage supply pressure to characterize the performance of the regulators beyond the current performance standards. These extended tests were not part of the acceptance criteria.

A hierarchical series of standardized testing[3] was conducted on each candidate regulator. Dry bench testing was first conducted to determine if the candidate regulators met the manufacturer's specifications for air delivery. Inhalation pressures were recorded at 141 SLM ± 1 SLM (5 SCFM) increments from 0 to 849 SLM (0 to 30 SCFM) of flow. A mean of the inhalation pressure (± 1 standard deviation) was derived from five test regulators per candidate model. Bench testing was terminated if cracking pressure varied from manufacturer's specifications by ± 0.13 kPa (0.50 inches of water).

A mechanical breathing simulator (Reimers Consultants, Falls Church, VA) provided sinusoidal breathing loops with RMV's ranging from 40 to 90 L/min, thus emulating varied diver work rates. Supply pressure to the first stage was maintained at 10.34 MPa (1500 psi) for the downward excursion, then reduced to 3.44 MPa (500 psi) to simulate worst case, for the upward excursion. Work of Breathing loops were taken at 10 msw (33 fsw) increments in both conditions. Test depths ranged from 0 to 60 msw (0 to 198 fsw). Water temperature was maintained at ambient, approximately 21°C (70°F).

Testing at a specific RMV/depth parameter was terminated if inhalation or exhalation pressure exceeded 4 kPa, the working limits of the pressure transducers currently used in the Experimental Diving Facility. Additionally, if two regulators of one model exceeded 4 kPa within the Performance Goal Standard RMV/depth parameter, testing of that model was terminated.

Descriptive statistics were used to obtain the mean and standard deviation of the data. To determine acceptability of WOB values that were slightly higher than Performance Goal Standard, a one sample T-test with significance established at $P < 0.05$ was performed.

RESULTS

Dry bench testing of candidate regulators revealed that the PDXL 700 delivered an average of 707 SLM (25 SCFM) at a high average inhalation pressure of 1.10 kPa (4.3 inches of water). Additionally, only one of the candidate regulators of this model was capable of delivering 849 SLM (30 SCFM). The PDXL 1000 was capable of delivering an average of 707 SLM (25 SCFM) at an average inhalation pressure of 1.02 kPa (4 inches of water). Additionally, only two of this model's candidate regulators was capable of delivering 849 SLM (30 SCFM). Flow characteristics for the PDXL 700 are shown in Figure 1. Figure 2 shows the flow characteristics for the PDXL 1000.

WOB values for the PDXL 700 at 10.34 MPa (1500 psi) supply pressure are summarized in Table 1 and Figure 3. At 40 RMV, WOB values exceed Performance Goal Standard at 10 msw (33 fsw), and continue to increase with each incremental increase in test depth, to a maximum attainable test depth of 40 msw (132 fsw). At 62.5 and 75 RMV, WOB values are beyond Performance Goal Standard at 0 msw, and increase markedly to maximum attainable test depths of 30 and 20 msw (99 and 66 fsw) respectively. WOB values were unattainable at the extreme ventilatory rate of 90 L/min. Due to the extremely high WOB values attained with two candidate regulators at the 10.34 MPa (1500 psi) supply pressure, any further testing of this model was terminated.

Table 2 and Figure 4 summarizes WOB values for the PDXL 1000 at 10.34 MPa (1500 psi) supply pressure. Performance Goal Standard was exceeded at 40 RMV and above from 0 to 60 msw (0 to 198 fsw). At 62.5 RMV, termination criteria was met at 30 msw (99 fsw). For the higher ventilatory rates of 75 and 90 L/min, termination criteria was met at 20 msw (66 fsw). Due to the extremely high WOB values attained with two candidate regulators at the 10.34 MPa (1500 psi) supply pressure, any further testing of this model was terminated.

MANNED EVALUATION

Due to the extremely poor performance evidenced during the unmanned testing phase, no manned testing was conducted for either candidate model regulator.

CONCLUSIONS/RECOMMENDATIONS

It is important to note that the establishment of performance criteria to 60 msw (198 fsw) is solely a Navy requirement and is not an endorsement by NEDU that casual/standard SCUBA dives be conducted to such depths with these regulators. Additionally, performance goals are not acceptance criteria for diving equipment approval and diving equipment that exceed these goals are not necessarily unsafe for diver use.

Work of Breathing results obtained from the PDXL 700 clearly identify this as a sub-standard performing regulator, not capable of meeting Performance Goal Standard at any depth or ventilatory rate. Based on the results obtained during unmanned evaluations of the PDXL 700, NEDU recommends that this regulator be excluded from the ANU list.

Work of Breathing results obtained from the PDXL 1000 show that this regulator also is not capable of meeting the performance criteria of the US Navy. Based on the results obtained during the unmanned evaluations of the PDXL 1000, NEDU recommends that this regulator be excluded from the ANU List.

REFERENCES

1. J. R. Middleton and E. D. Thalmann, *Standardized NEDU Unmanned UBA Test Procedures and Performance Goals*, NEDU TR 3-81, Navy Experimental Diving Unit, July 1981.

2. NAVSEA Task 94-010, *Commercial Diving Equipment Test and Evaluation*, January, 1994.

3. *Evaluation of Commercial Open Circuit SCUBA Regulators (Unmanned/Manned)*, NEDU Test Plan 93-21 (Limited Distribution), Navy Experimental Diving Unit, May 1993.

4. *Evaluation of Commercial SCUBA Regulators OSF Bounce Dive Series to 190 FSW (Manned)*, NEDU Test Plan 92-44 (Limited Distribution), Navy Experimental Diving Unit, November 1992.

TABLE 1

PDXL 700 OPEN CIRCUIT SCUBA REGULATOR WOB RESULTS MEAN ± 1 STANDARD DEVIATION EXPRESSED IN JOULES PER LITER (J/L)

10.34 MPa (1500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	1.28 ± 0.14	1.72 ± 0.19	1.98 ± 0.21	#
10	1.66 ± 0.23	2.28 ± 0.27	2.81 ± 0.26	#
20	1.90 ± 0.20	3.03 ± 0.29	3.96 ± 0.27	#
30	2.19 ± 0.23	3.93 ± 0.31	#	#
40	2.51 ± 0.23	#	#	#
50	#	#	#	#
60	#	#	#	#

# Denotes WOB value beyond termination criteria

TABLE 2

PDXL 1000 OPEN CIRCUIT SCUBA REGULATOR WOB RESULTS MEAN ± 1 STANDARD DEVIATION EXPRESSED IN JOULES PER LITER (J/L)

10.34 MPa (1500 PSI) SUPPLY PRESSURE

DEPTH IN METERS	RESPIRATORY MINUTE VOLUME			
	40	62.5	75	90
0	1.42 ± 0.08	1.90 ± 0.07	2.18 ± 0.10	2.57 ± 0.05
10	1.96 ± 0.14	2.68 ± 0.07	3.24 ± 0.11	3.93 ± 0.10
20	2.19 ± 0.14	3.35 ± 0.07	4.20 ± 0.21	#
30	2.51 ± 0.14	4.14 ± 0.24	#	#
40	2.81 ± 0.19	#	#	#
50	3.12 ± 0.14	#	#	#
60	3.48 ± 0.21	#	#	#

# Denotes WOB value beyond termination criteria

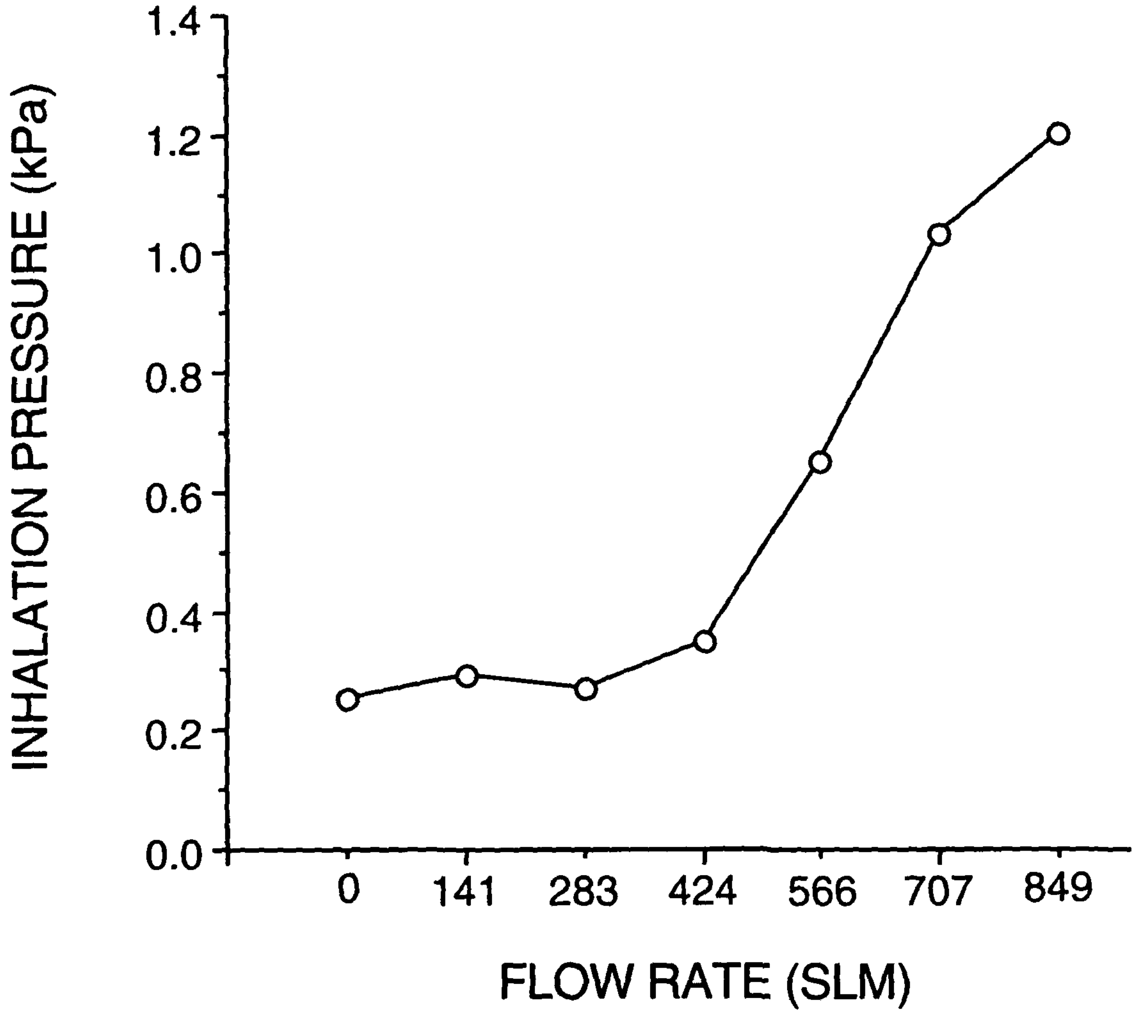

Figure 1. PDXL 700 Flow Characteristics

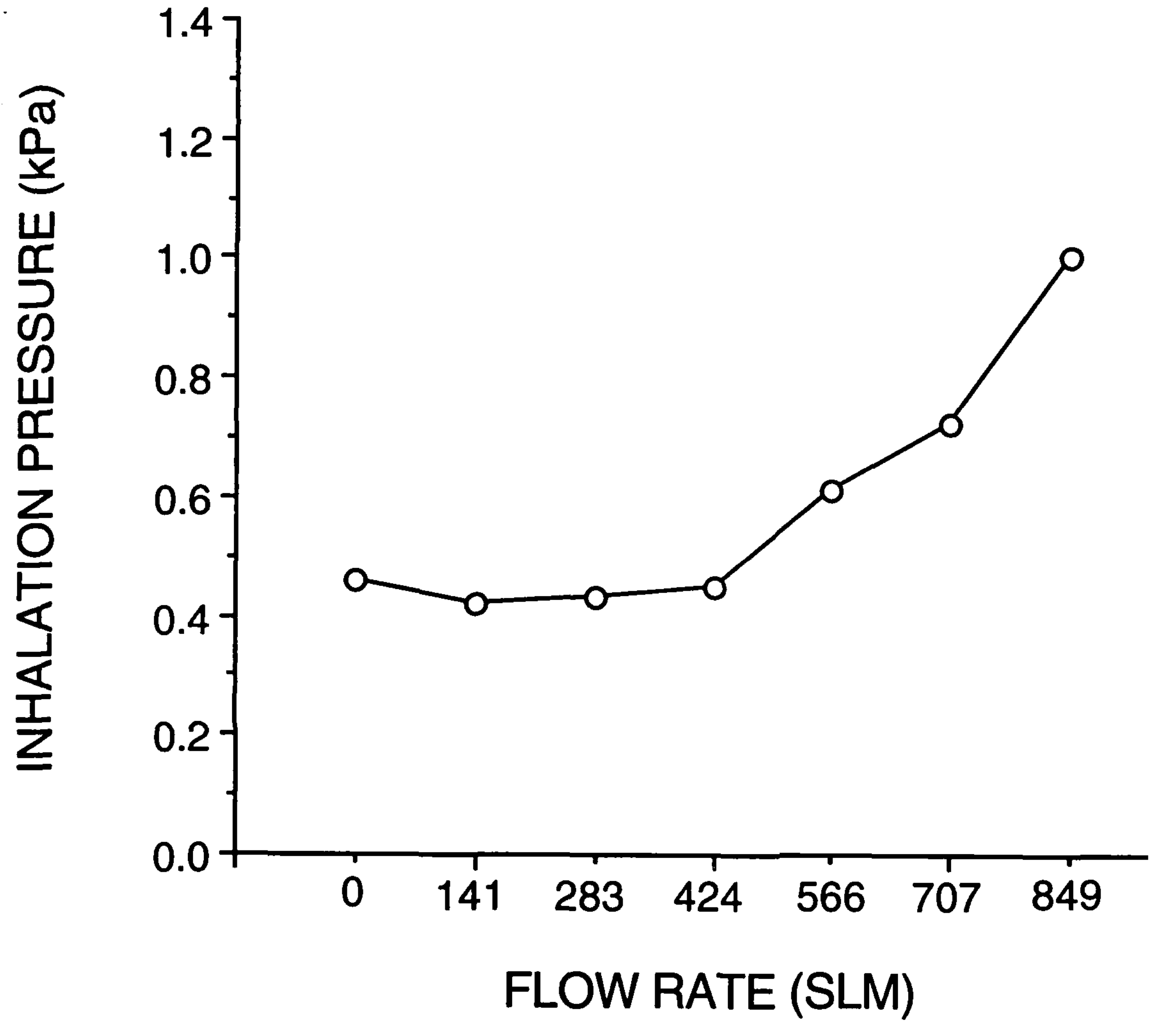

Figure 2. PDXL 1000 Flow Characteristics

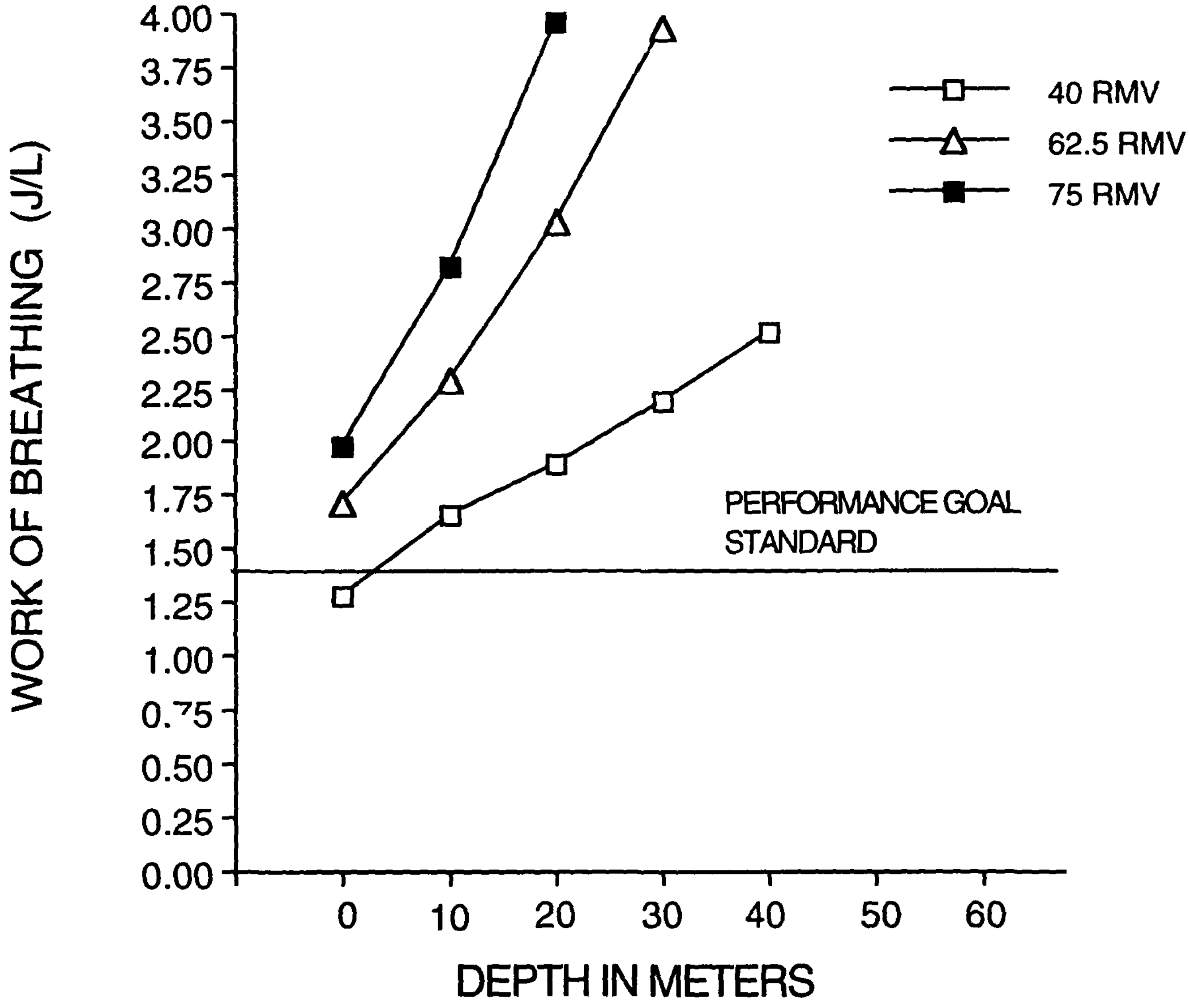

Figure 3. PDXL 700, 10.34 MPa (1500 psi) Supply Pressure

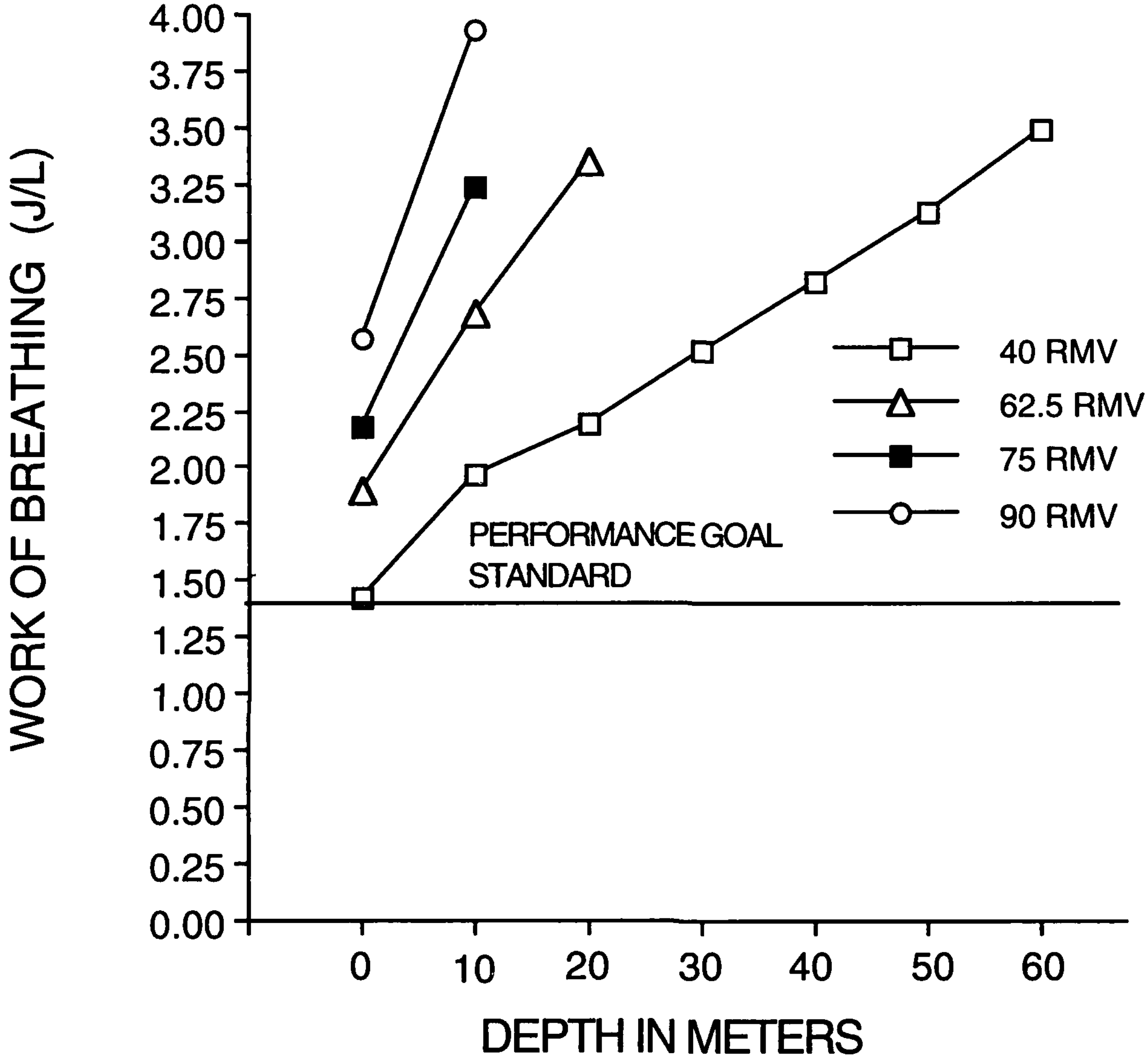

Figure 4. PDXL 1000, 10.34 MPa (1500 psi) Supply Pressure